Organized Multi-scale Precipitating Convection and the Global Circulation

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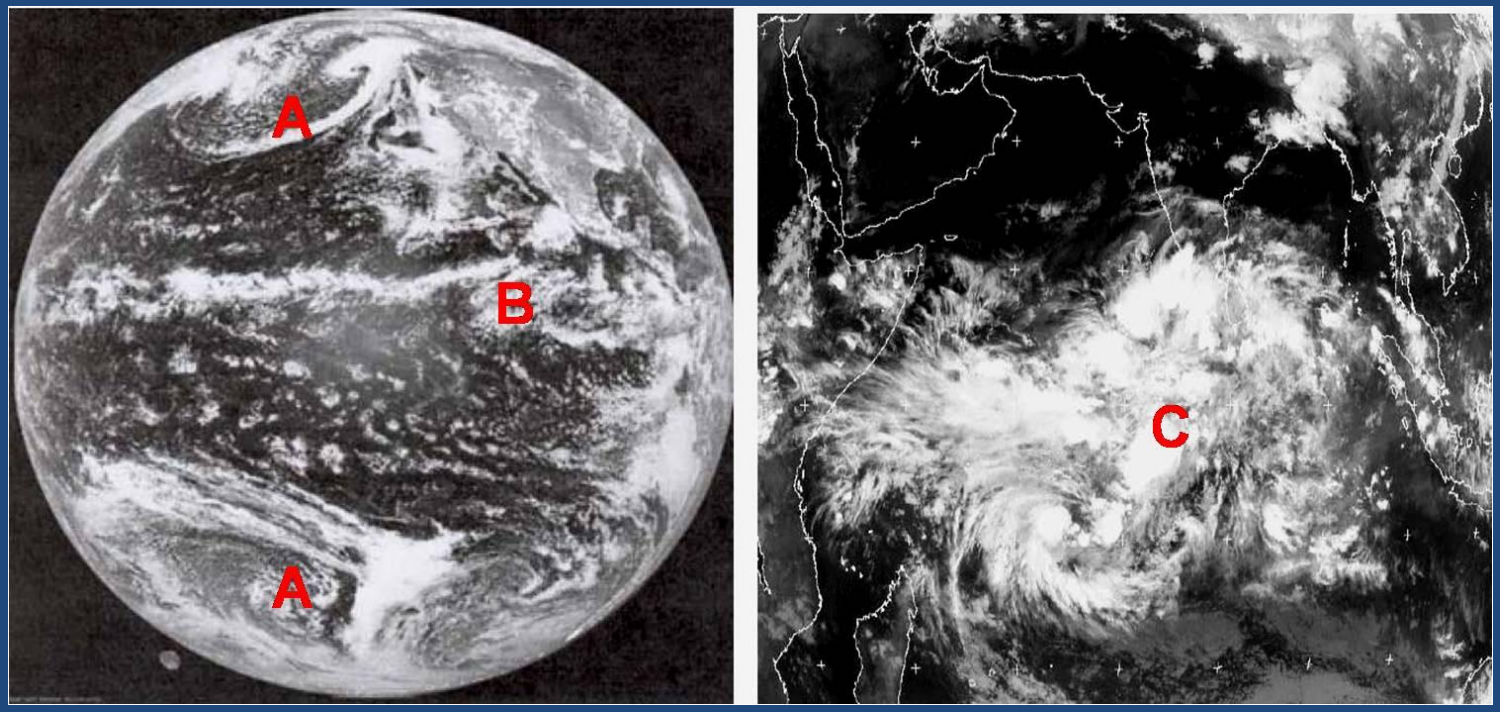
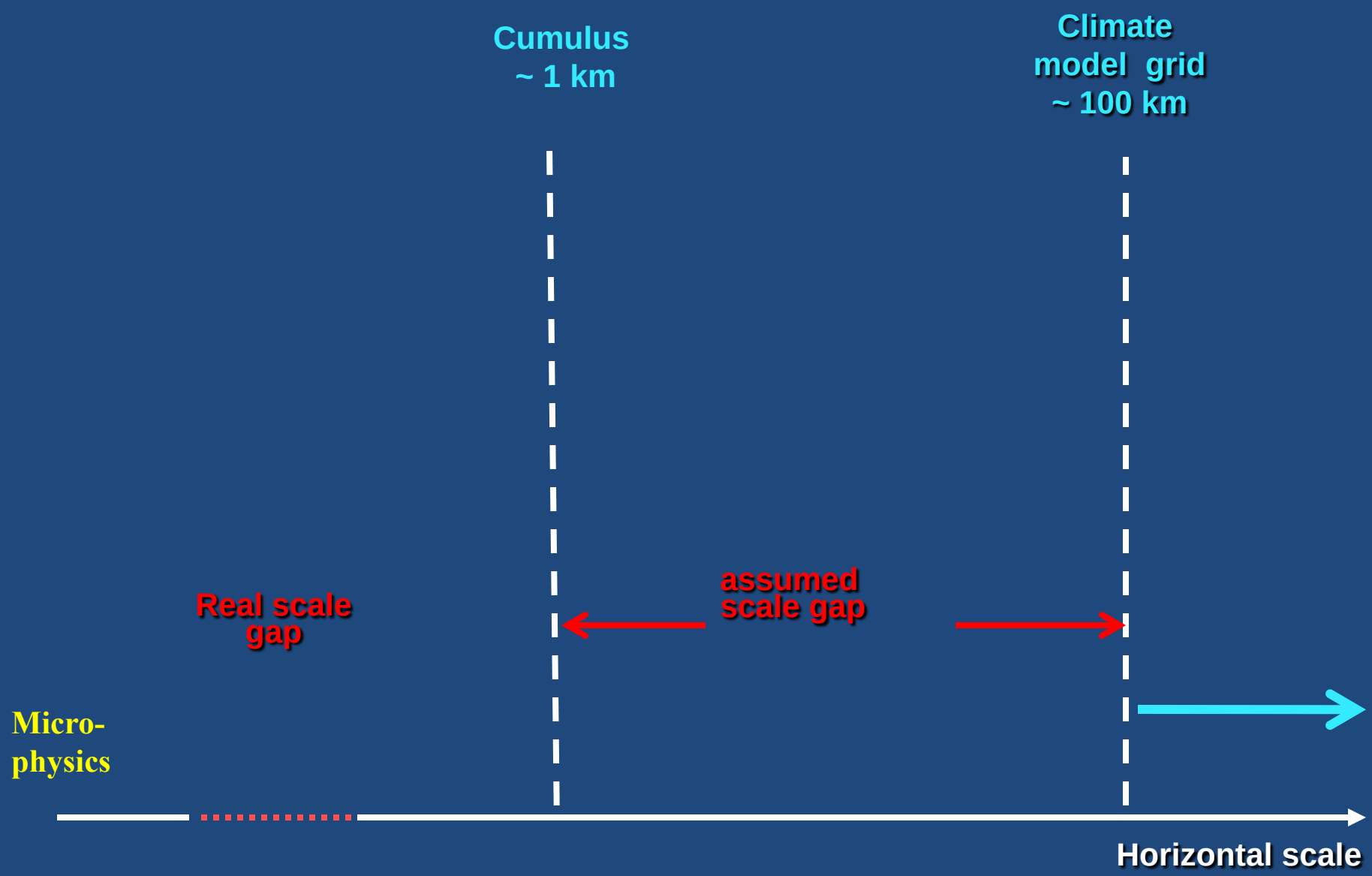


Workshop on *High-resolution Climate Modeling,* International Centre for Theoretical Physics, Trieste, Italy, August 10-14, 2009

Organized convection and global models

- The amount and distribution of precipitation is strongly affected by convective organization
- We know much about convective organization as a process, much less about its large-scale effects and, especially, how it is represented in global models
- This state-of-affairs is changing in accord with models with resolution high enough to explicitly represent the mesoscale circulations associated with

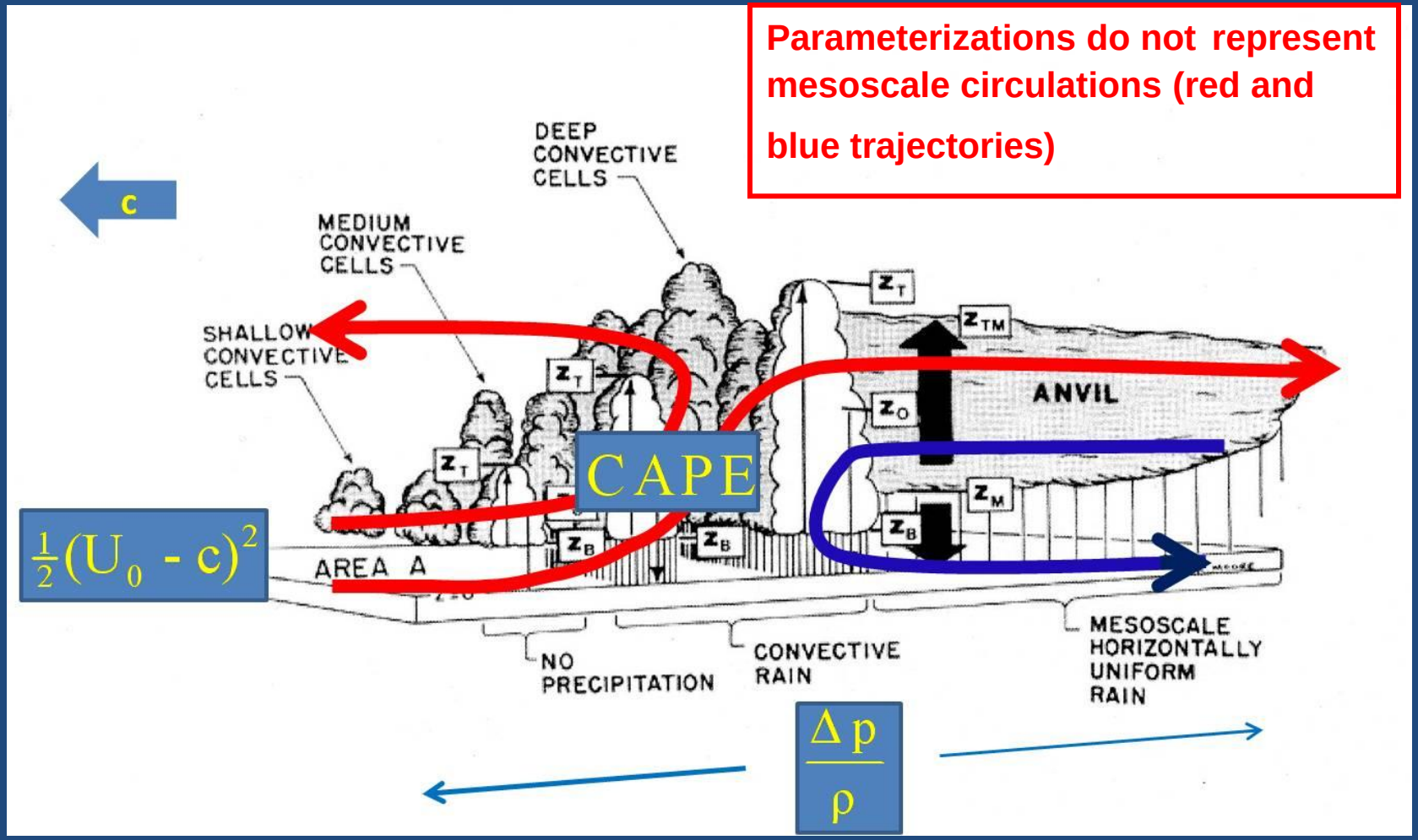


Traditional parameterization

Cumulus
~ 1 km
Climate model grid
~ 100 km
Meso-convective organization
Scale gap
Continuum: no scale gap
Microphysics
Horizontal scale
Reality

Three forms of energy

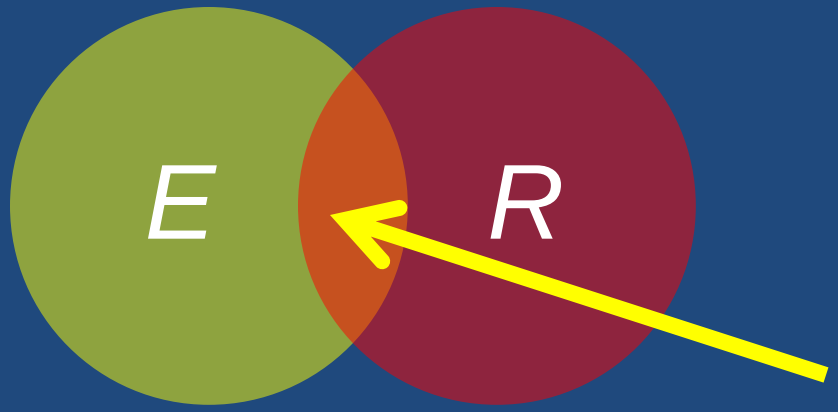
Parameterizations do not represent mesoscale circulations (red and blue trajectories)



The 3 energies (available potential energy; kinetic energy involving shear, work done by the pressure gradient) define 2 key quantities:

$$E = \frac{\Delta p}{\rho \frac{1}{2}(U_0 - c)^2}$$

$$R = \frac{CAPE}{\frac{1}{2}(U_0 - c)^2}$$



MCS- type convective organization

Traditionally:

Moist convection in global models represented solely by cumulus parameterization

Nowadays, explicit approaches:

- **Cloud-system resolving models (CRM; ~ 1 km grid) with computational domains up to global simulate meso-convective organization**

- **Large Eddy Simulation (LES; 100 m grids) resolves cumulus in domains ~ 200 km x 200 km**

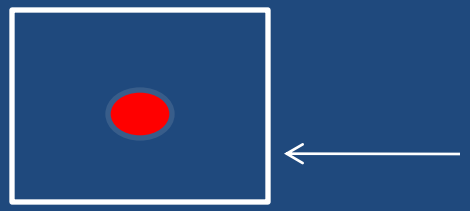
- **Global NWP models; grid-scale circulations (under-resolved organization) occur along with cumulus parameterization**

- **Super-parameterization: 2-D organization represented by CRMs**

Cumulus parameterization remains an issue for climate models

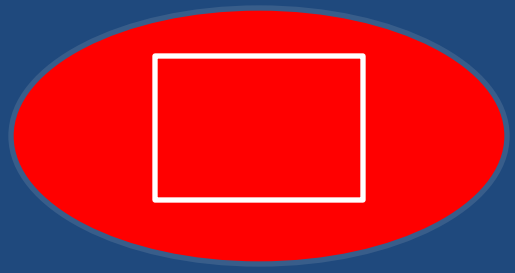
Representing convective cloud systems of scale L in numerical models with grid-length

a) Traditional parameterization



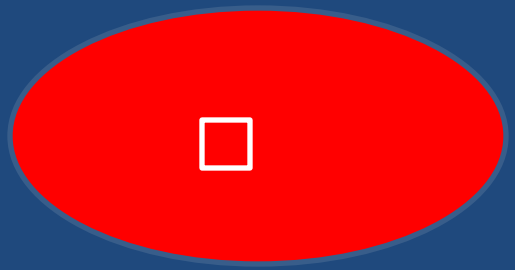
$\Delta \ll L$

b) Hybrid parameterization



$\Delta \sim L$

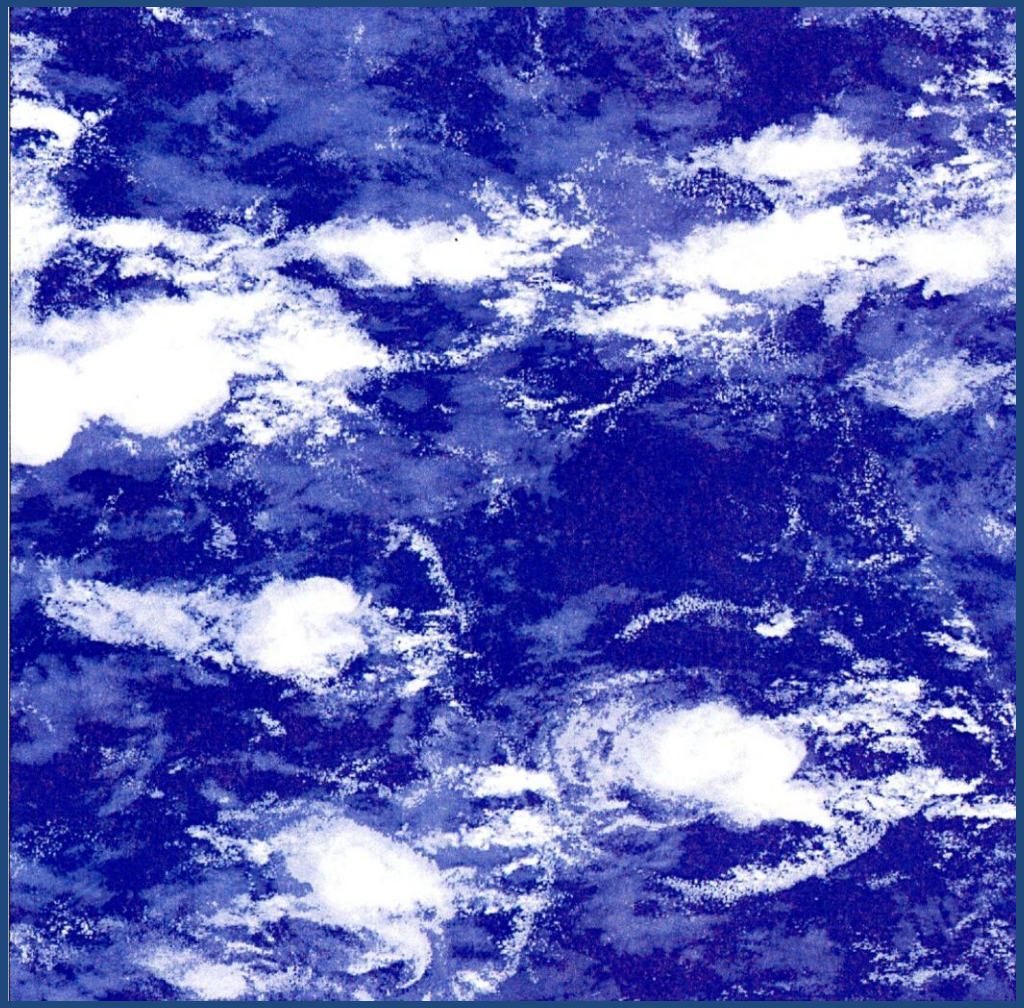
c) Explicit (CRM & LES)



$\Delta \ll L$

Convective organization simulated with 100-m grid, an LES/CRM approach

$\Delta \square$ L



Courtesy: Marat Khairoutdinov, SUNY/Stoney Brook & CMMAP

Weather as an initial-value problem for climate

Simulation of MJO with NICAM:

MJO event: 15 Dec 2006 – 15 Jan 2007

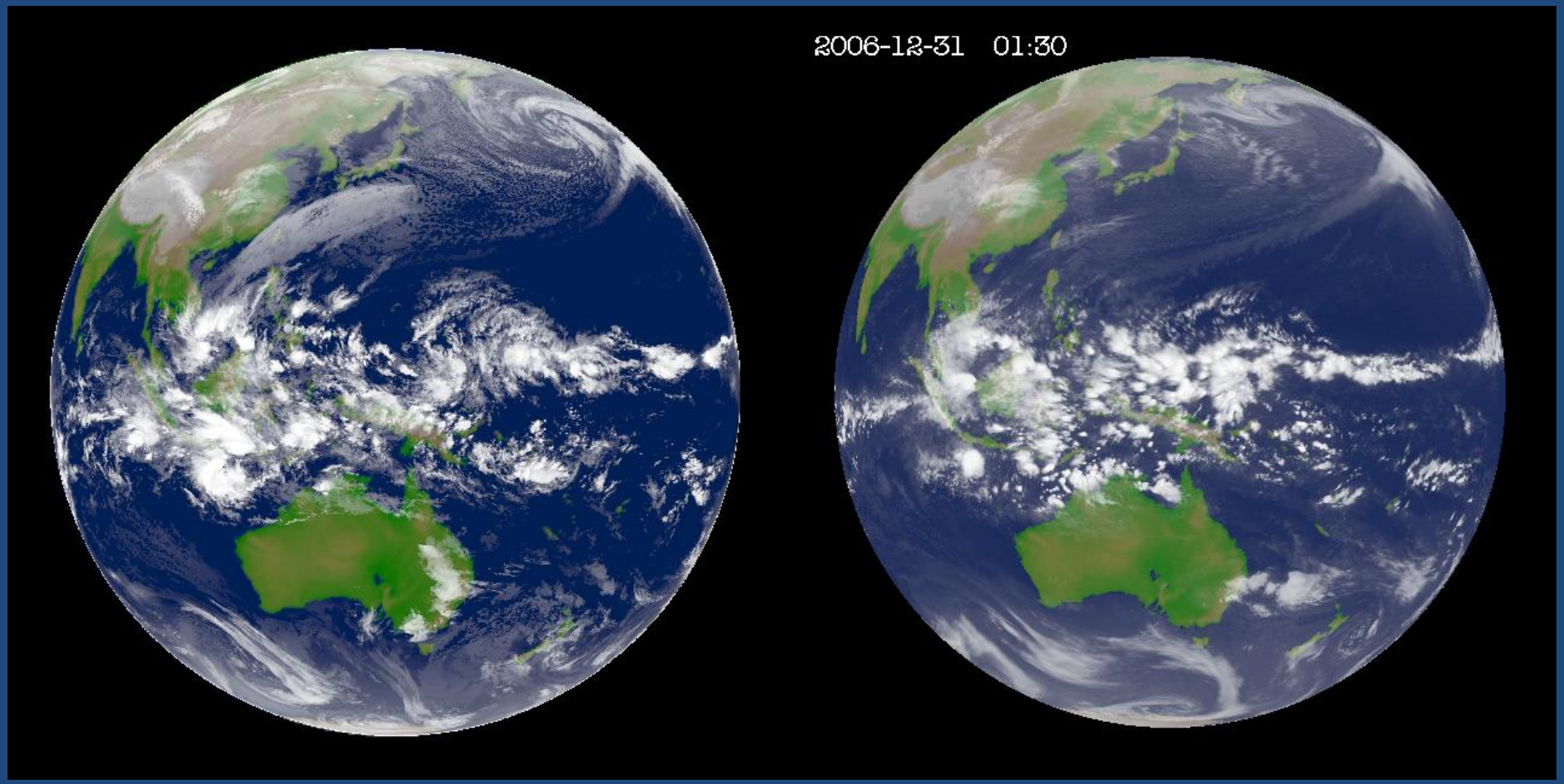
Specified SST

Courtesy: The NICAM Team

31DEC2006 09:00 JST

MTSAT-1R

3.5-km run



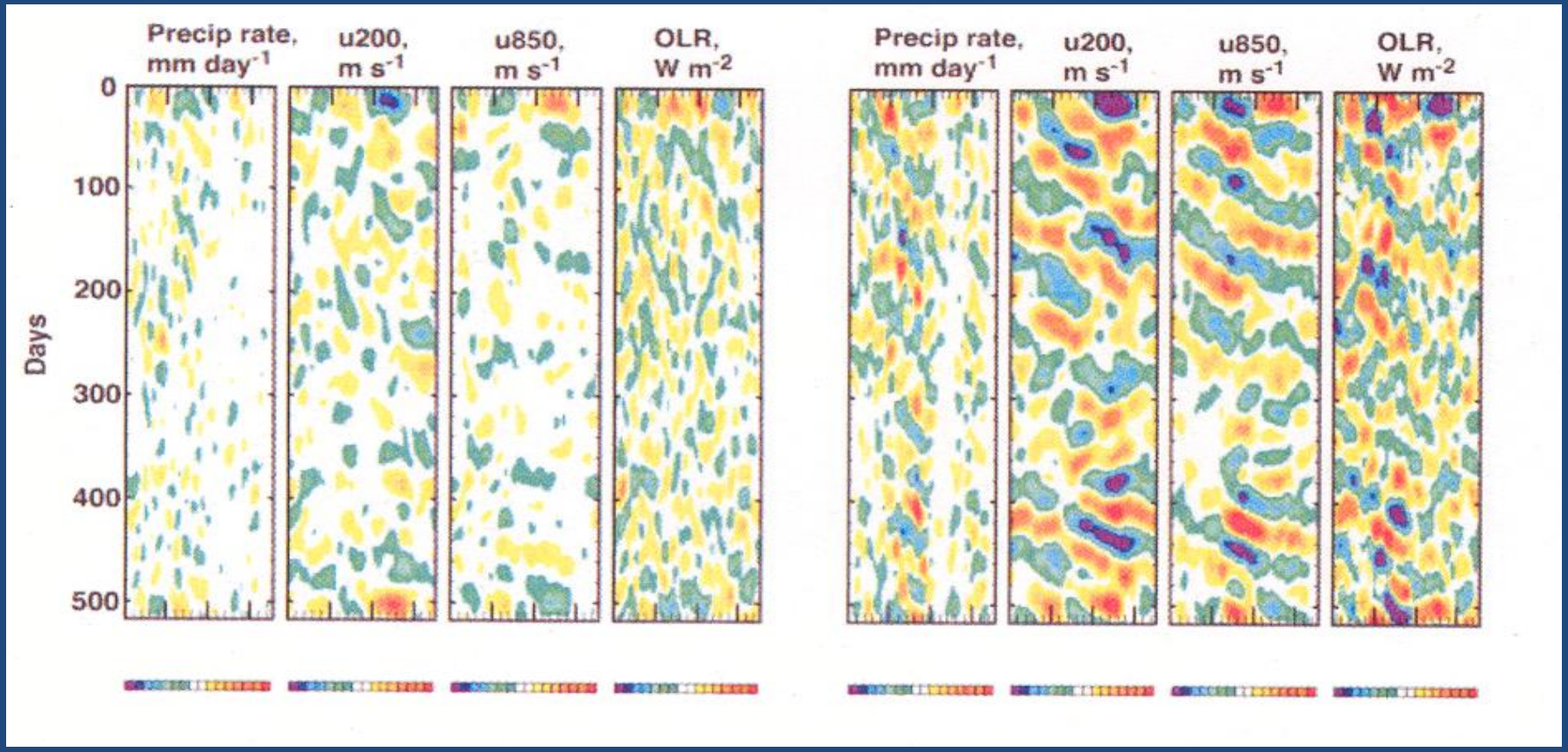
Courtesy: The NICAM Team, Japan

Superparameterization

MJO in the Community Atmospheric Model

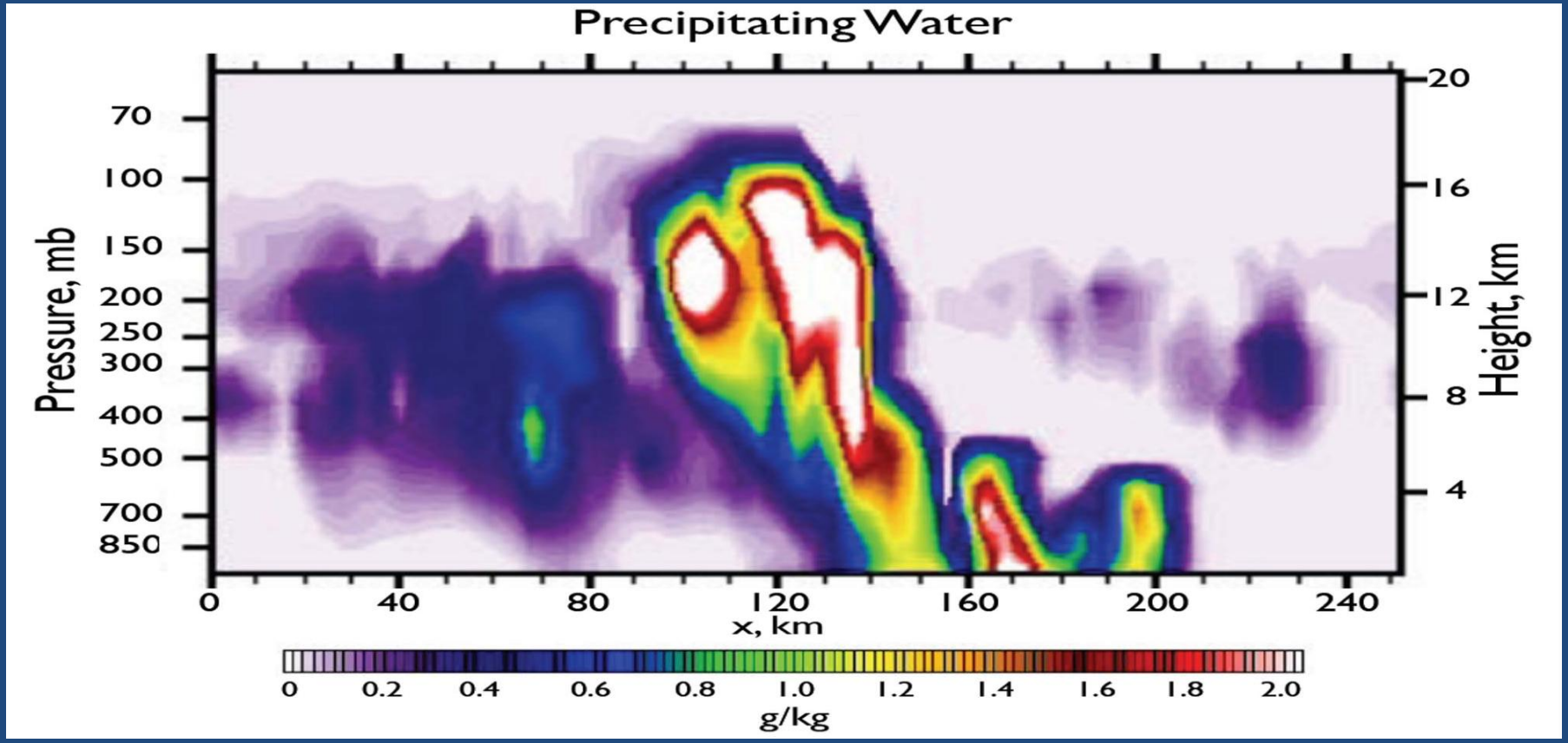
Conventional parameterization

Superparameterization



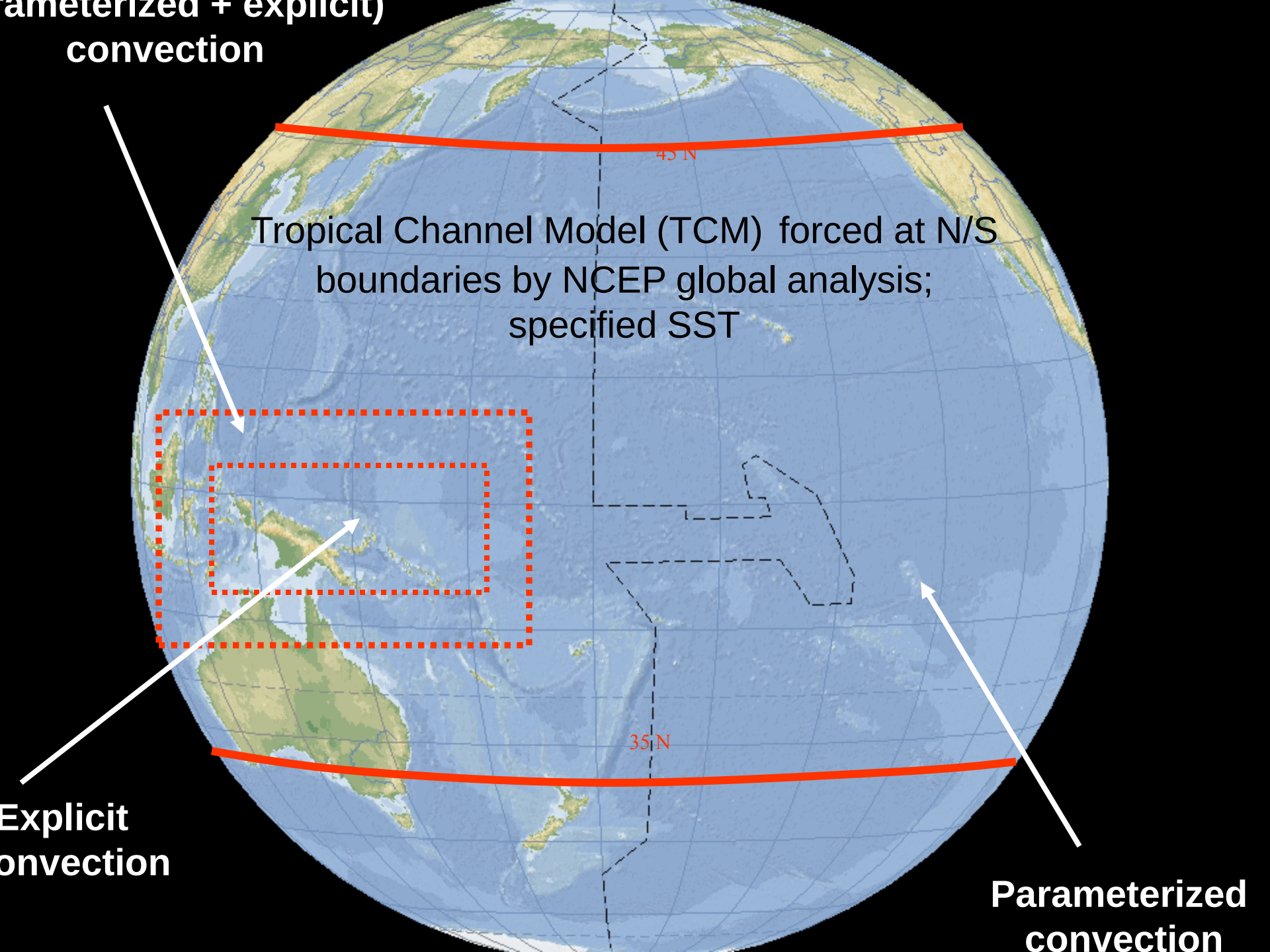
Khairoutkinov et al (2005)

MCS-like propagating systems in the CRM domains embedded in the global-grid

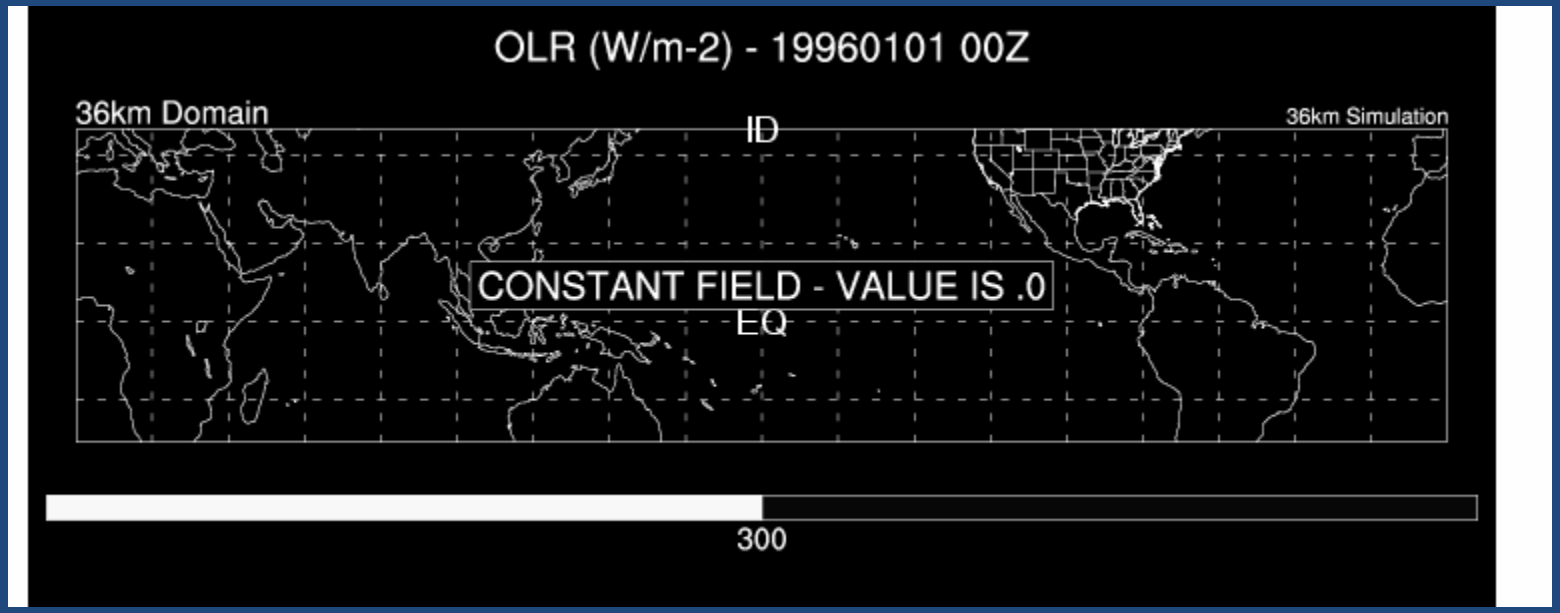


Courtesy: Marat Khairoutdinov

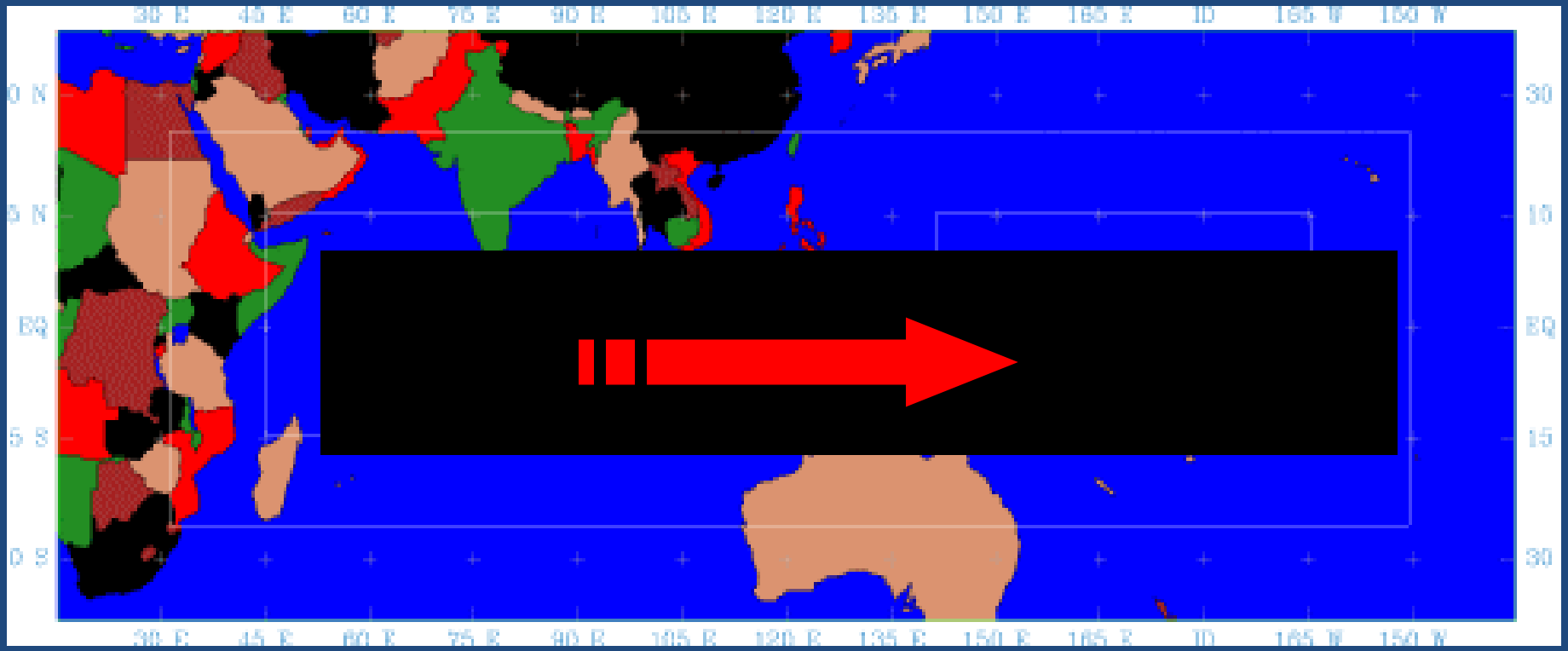
Nested Tropical Channel Modeling


ameterized + explicit)
convection
45 N
Tropical Channel Model (TCM) forced at N/S boundaries by NCEP global analysis; specified SST
35 N
Explicit
onvection
Parameterized
convection

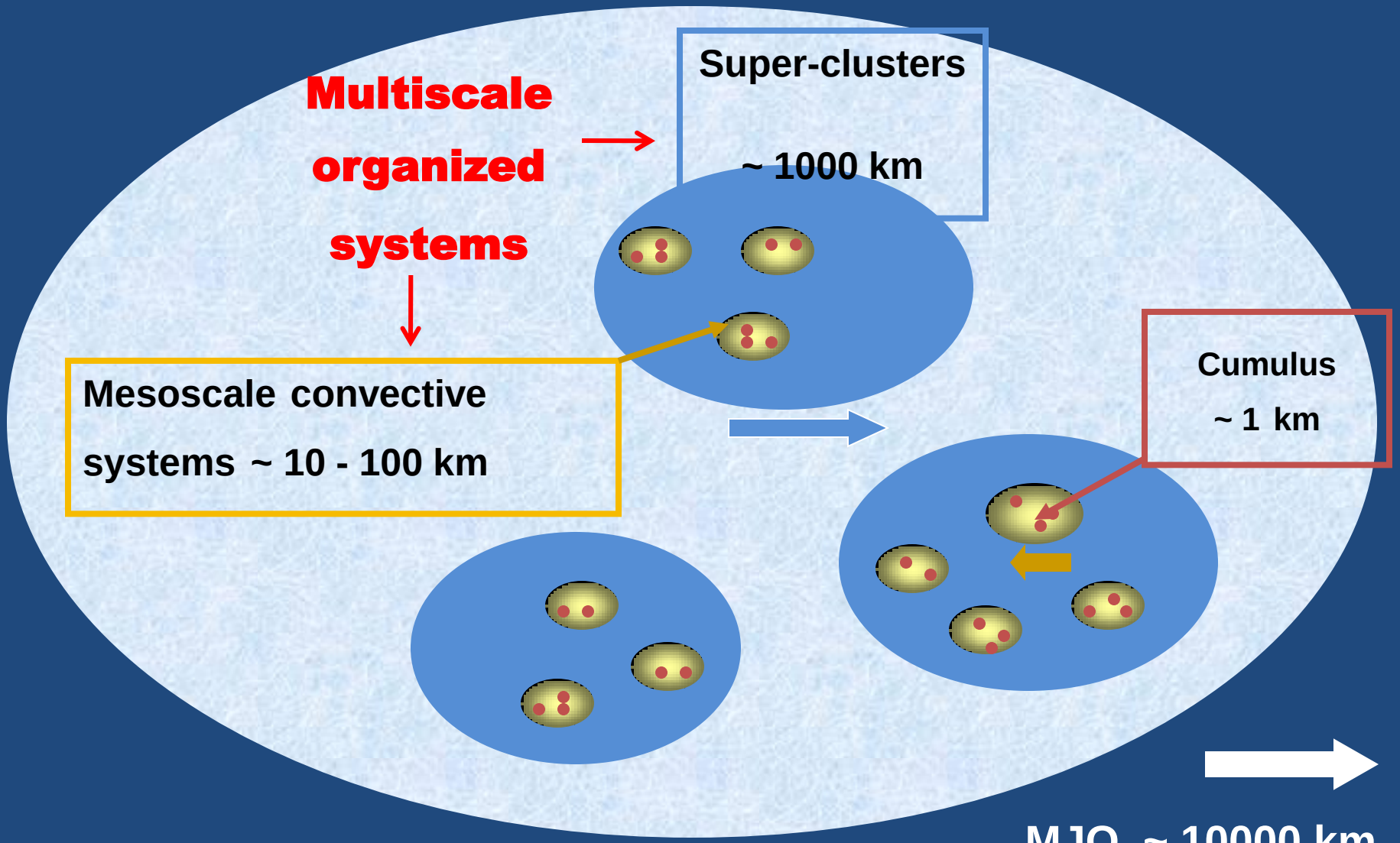
Tropical Channel Model (36-km grid)



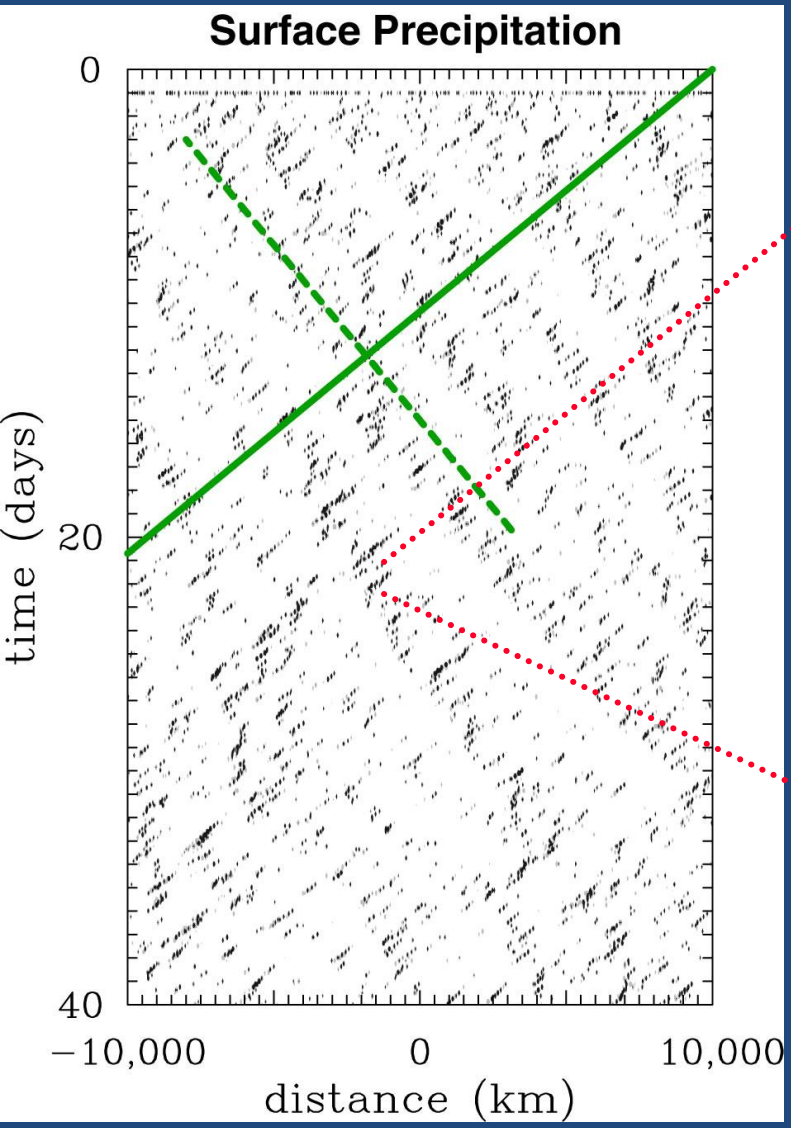
Upscale effects of organized convection and the MJO

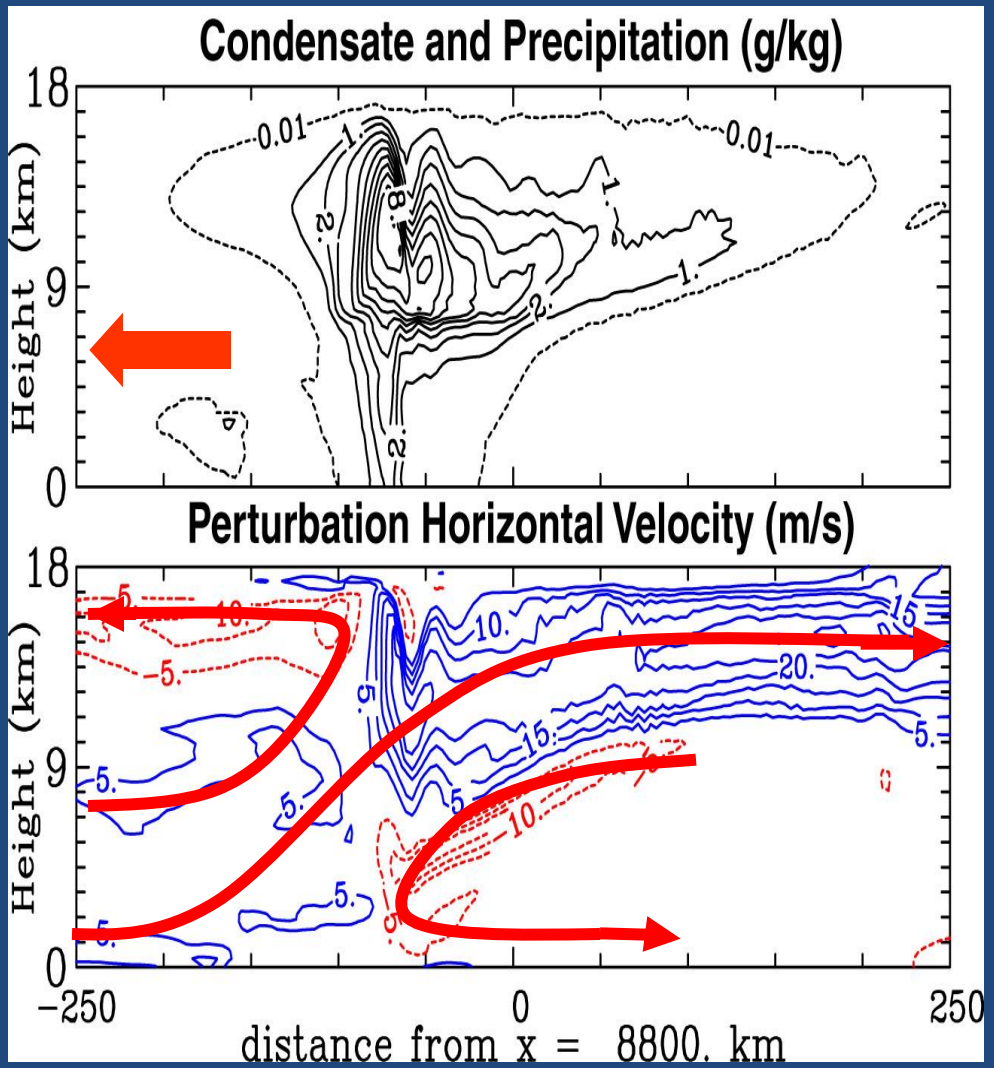

30 E
45 E
60 E
75 E
90 E
105 E
120 E
135 E
150 E
165 E
180
165 W
150 W
0 N
5 N
EQ
5 S
0 S
30
15
EQ
15
30

Can MJO evolve by virtue of an "upscale cascade" of energy and momentum?



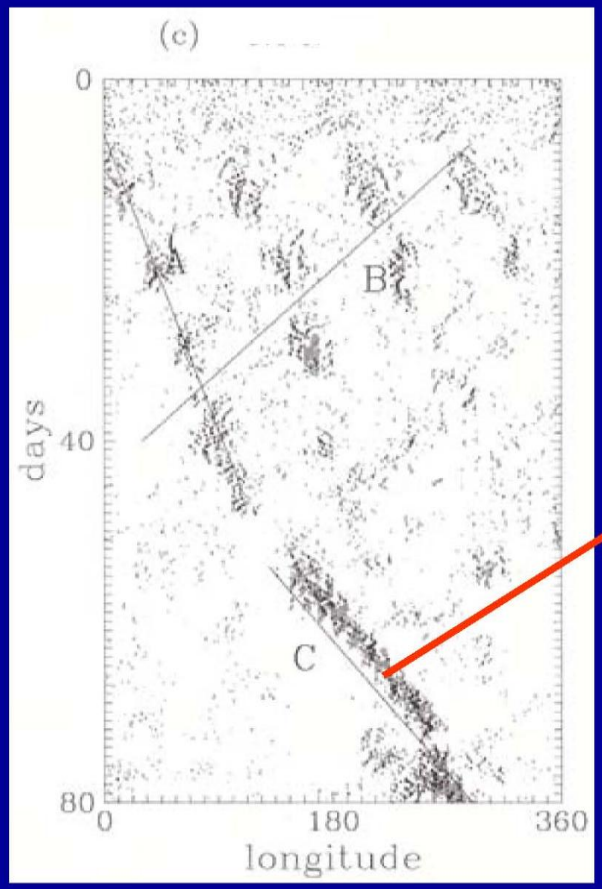
MCS-like & supercluster-like organization in a 2-D global-scale CRM

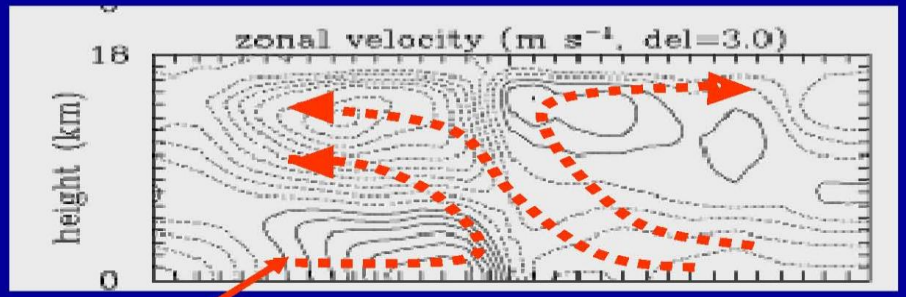




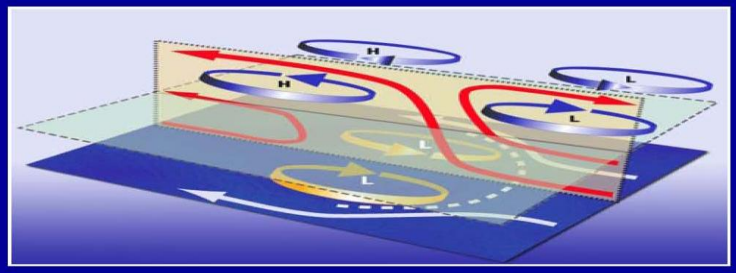
Grabowski and Moncrieff (2001)

MJO-like & supercluster-like organization in a superparameterized global model





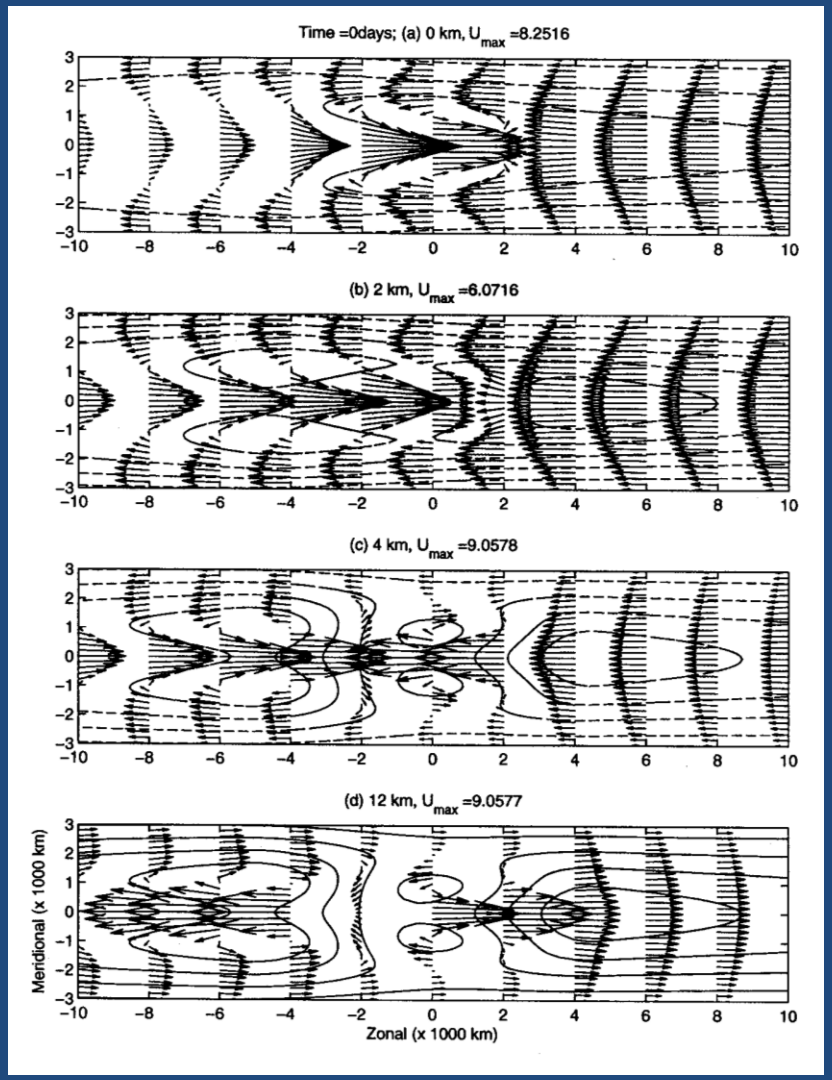
Vertical structure of the eastward propagating supercluster-like system



Dynamical model of organized convection interlocked with a Rossby-gyre circulation

Grabowski (2001)
Moncrieff (2004)

Upscale effects of MCS/superclusters on MJO



$$\bar{U}_t - y\bar{V} + \bar{P}_X = F^U - d_m\bar{U}$$

$$y\bar{U} + \bar{P}_y = 0$$

$$\bar{\theta}_t + \bar{W} = F^\theta - d_\theta + \bar{S}_\theta$$

$$\bar{P}_z = \bar{\theta}$$

$$\bar{U}_X + \bar{V}_y + \bar{W}_z = 0$$

$$F^U = -\overline{(v'u')}_y - \overline{(w'u')}_z$$

$$F^\theta = -\overline{(v'\theta')}_y - \overline{(w'\theta')}_z$$

Biello, Majda and Moncrieff (2007)

Comment . . .

- **We have still to demonstrate the upscale cascade hypothesis for the MJO operates in full-physics prediction models**

- **Being addressed by the UK *Cascade* project and by NCAR Channel Model experiments**

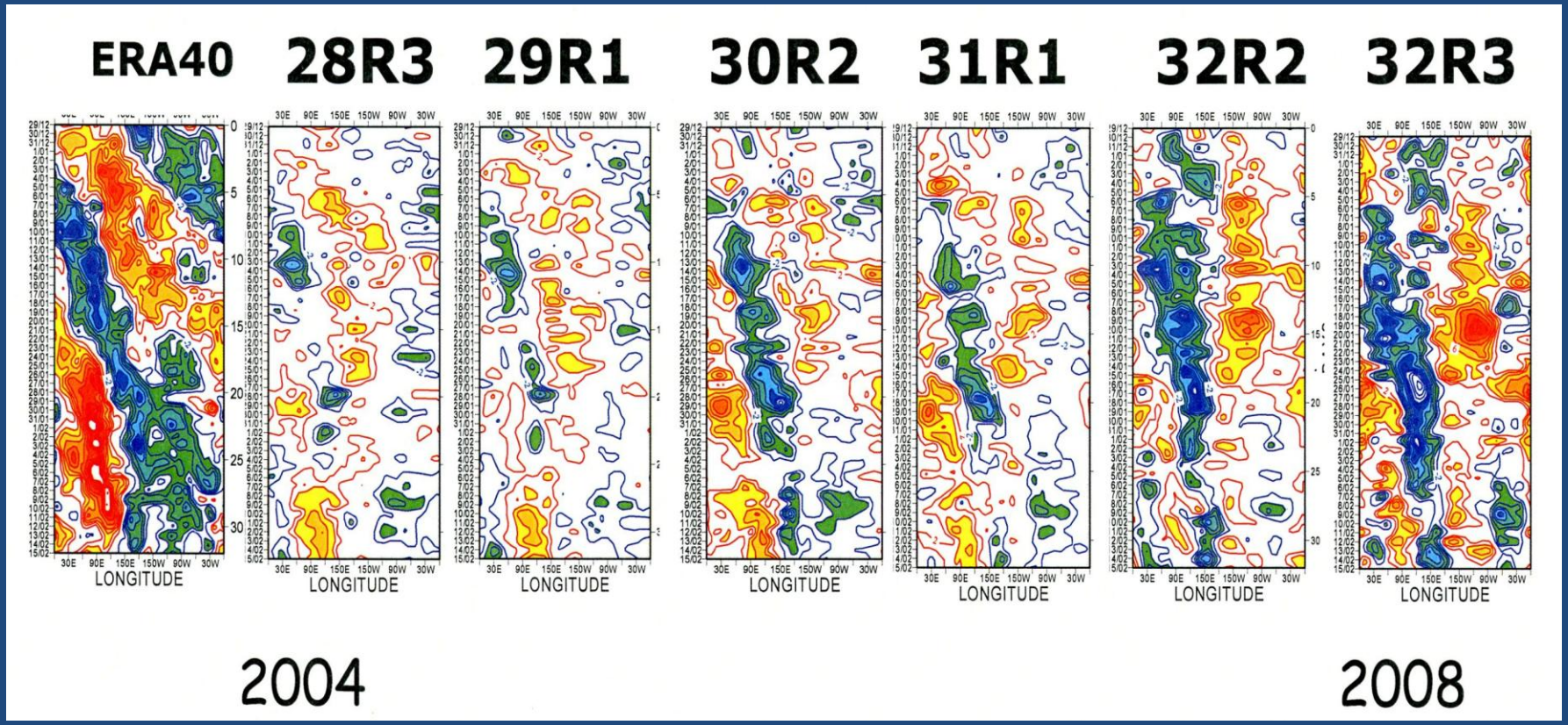
Improving convective parameterization

Representing MCS

$\Delta \square L$ **Climate models: traditional**

$\Delta \sim L$ **Weather models: hybrid**

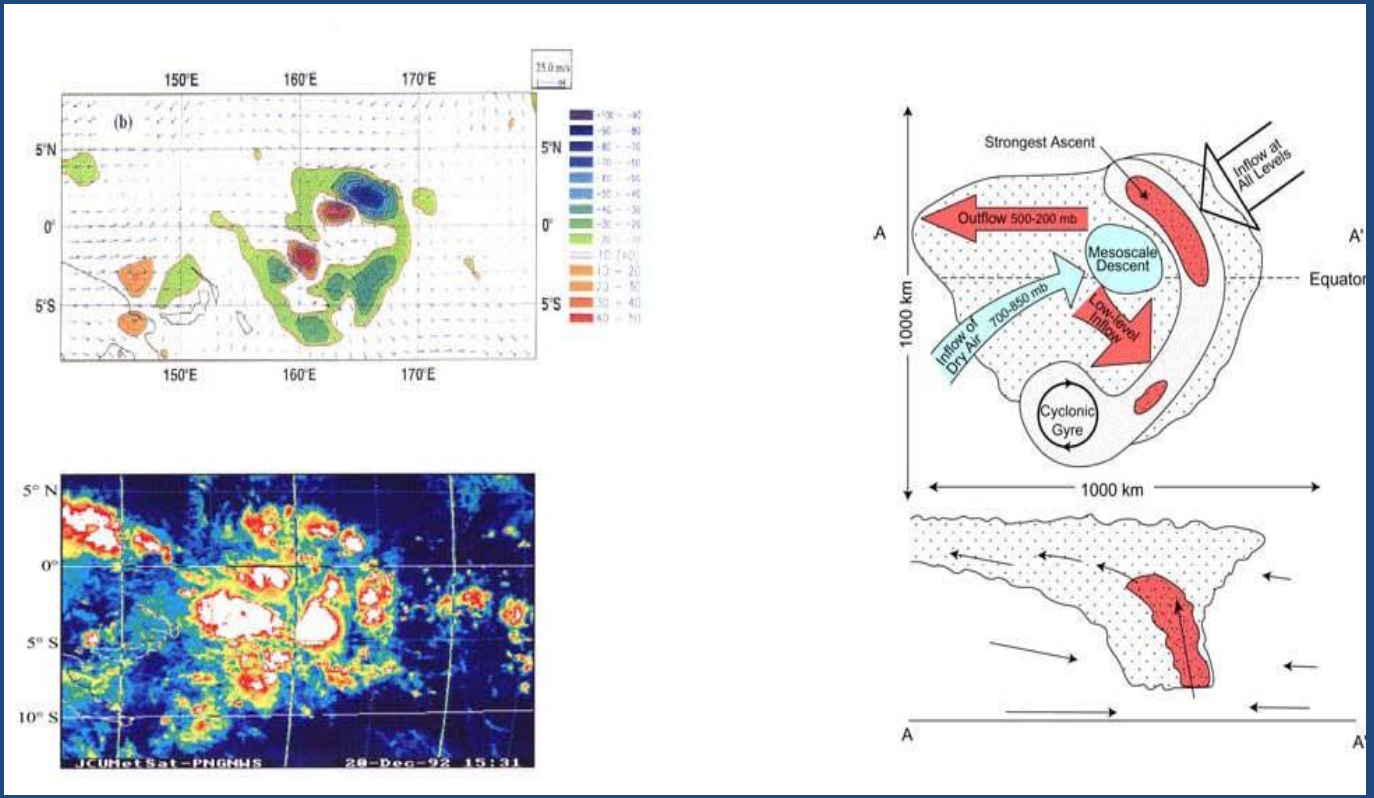
Improved MJO in ECMWF model



Do “grid-scale” circulations (under-resolved mesoscale organization) play a positive role? (Yes)

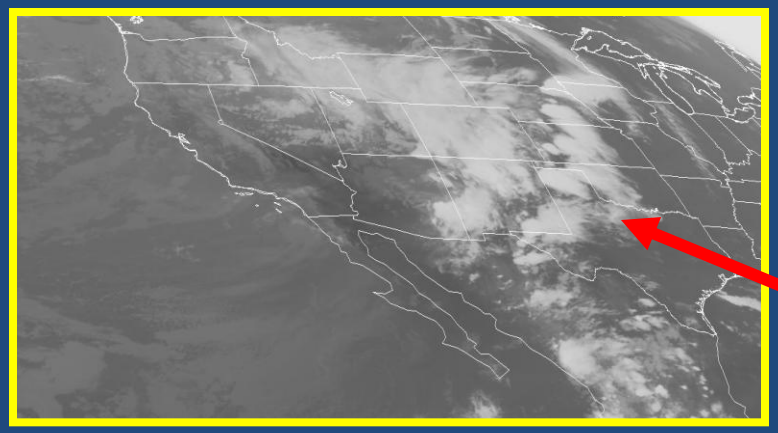
vs

Do convective parameterizations suppress organization? (Yes)

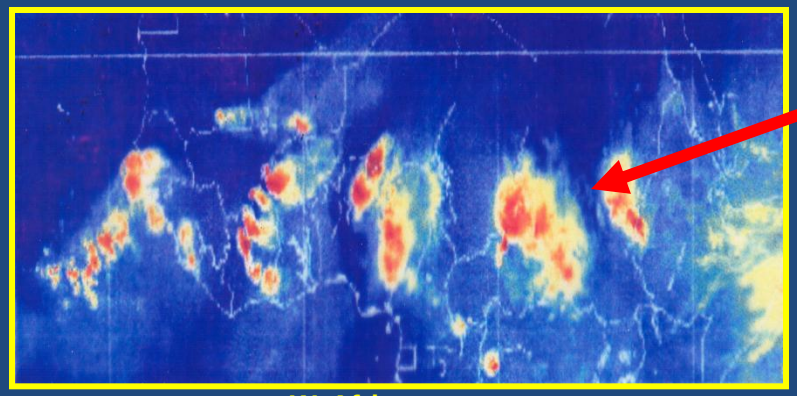


Moncrieff & Klinker (1997)

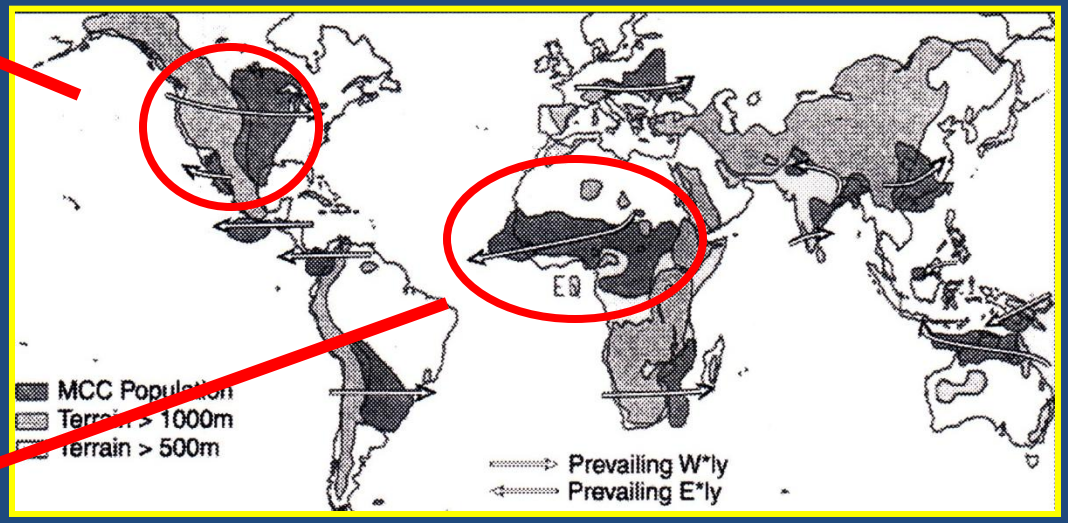
MCS downstream of mountains



Continental US

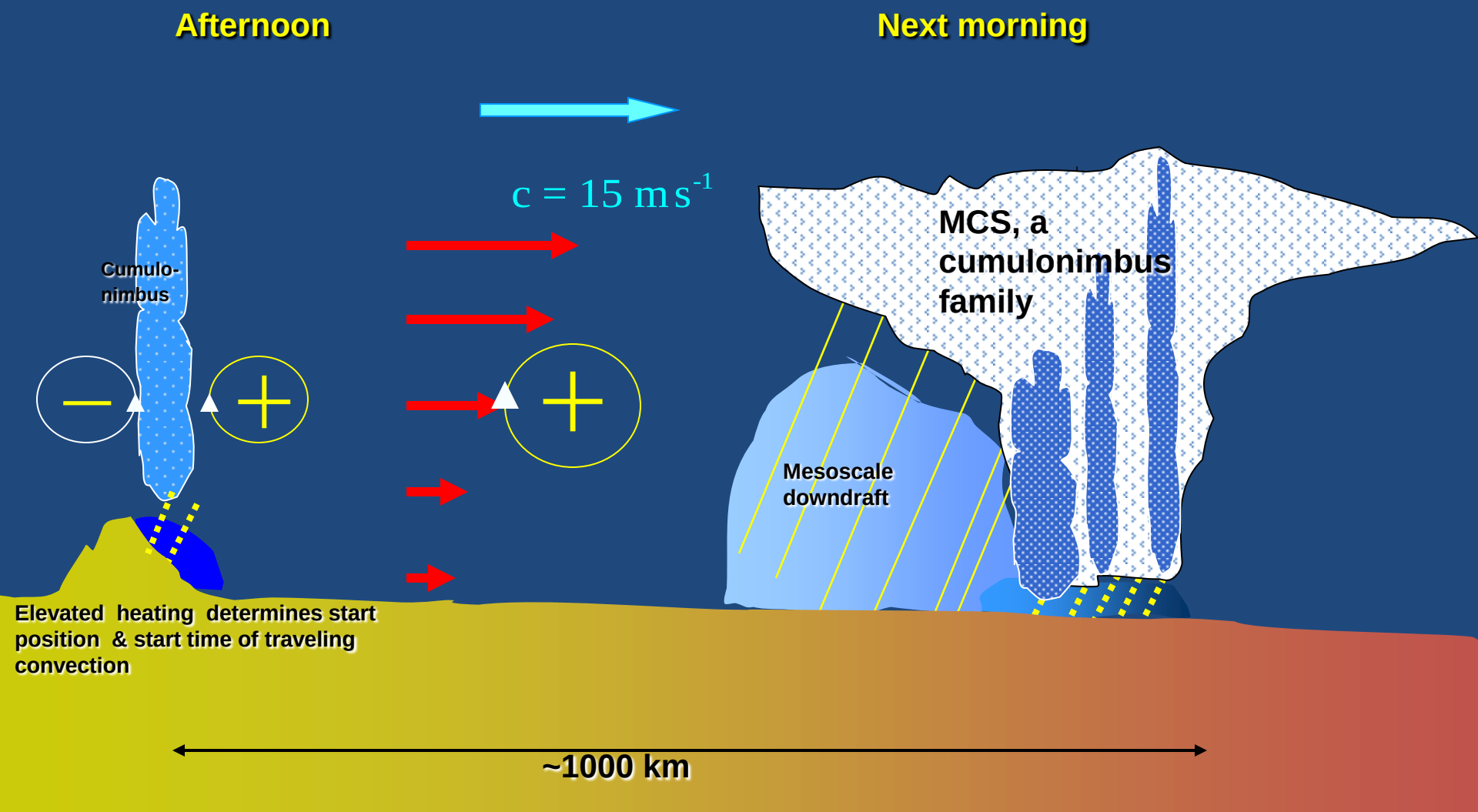


W. Africa

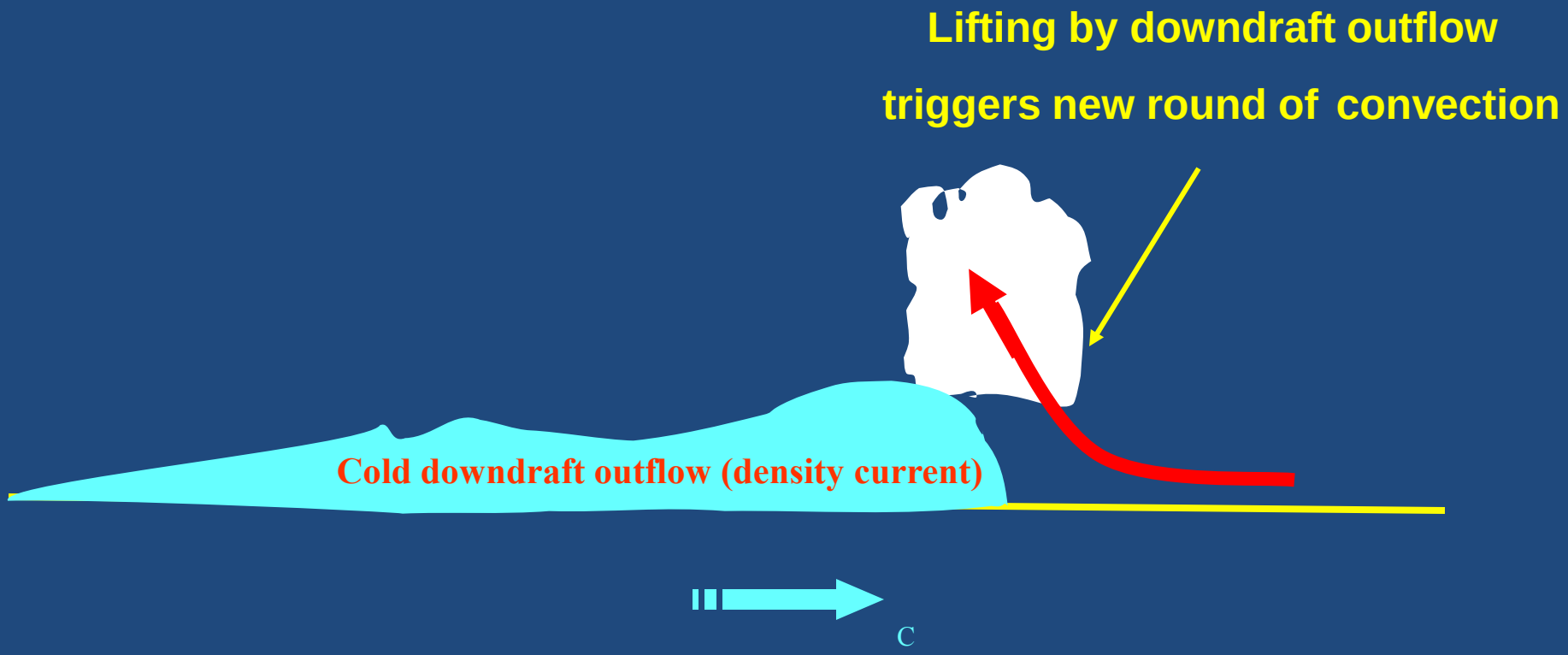


Laing and Fritsch (1997)

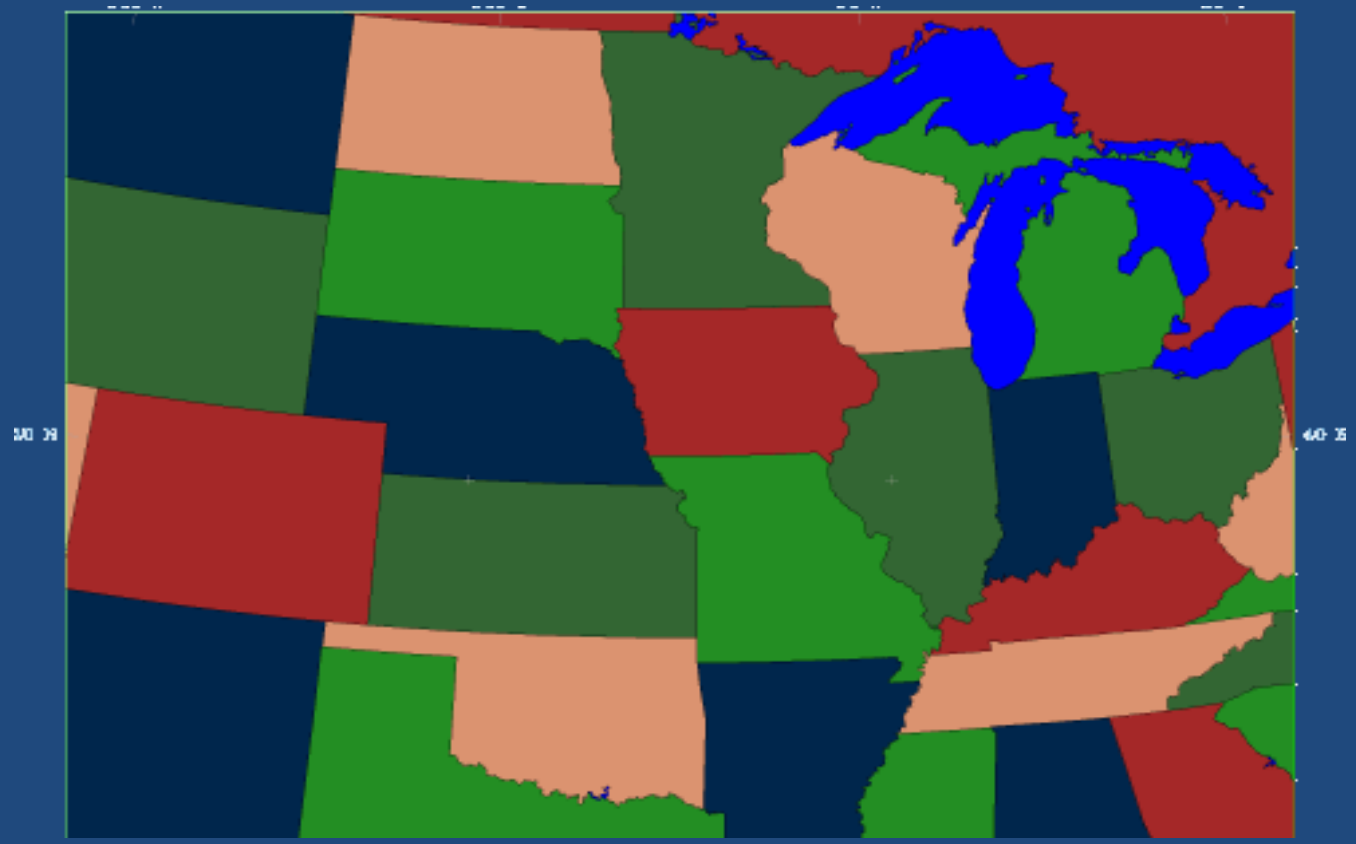
MCS downstream of mountains



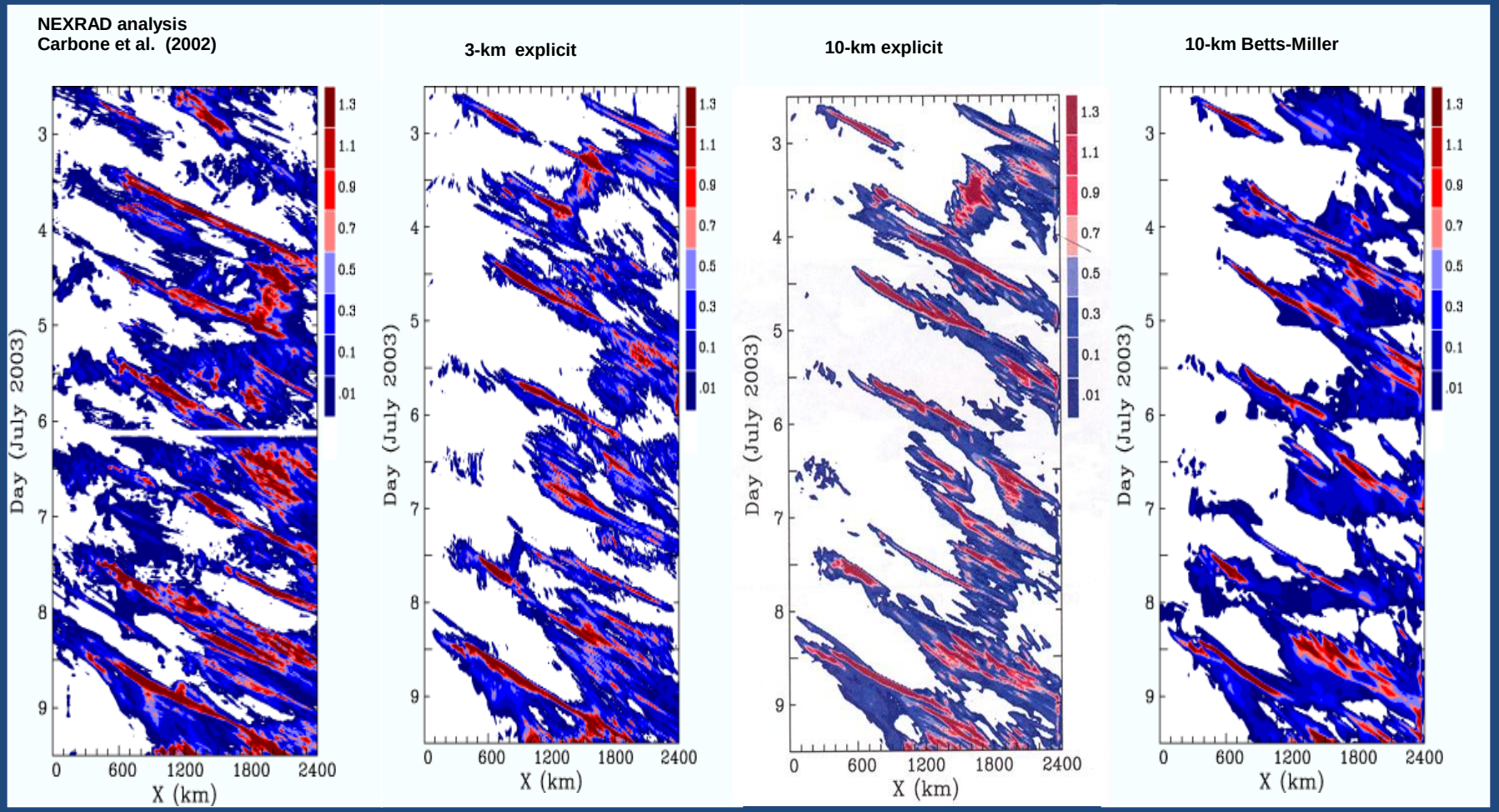
Downdraft triggering



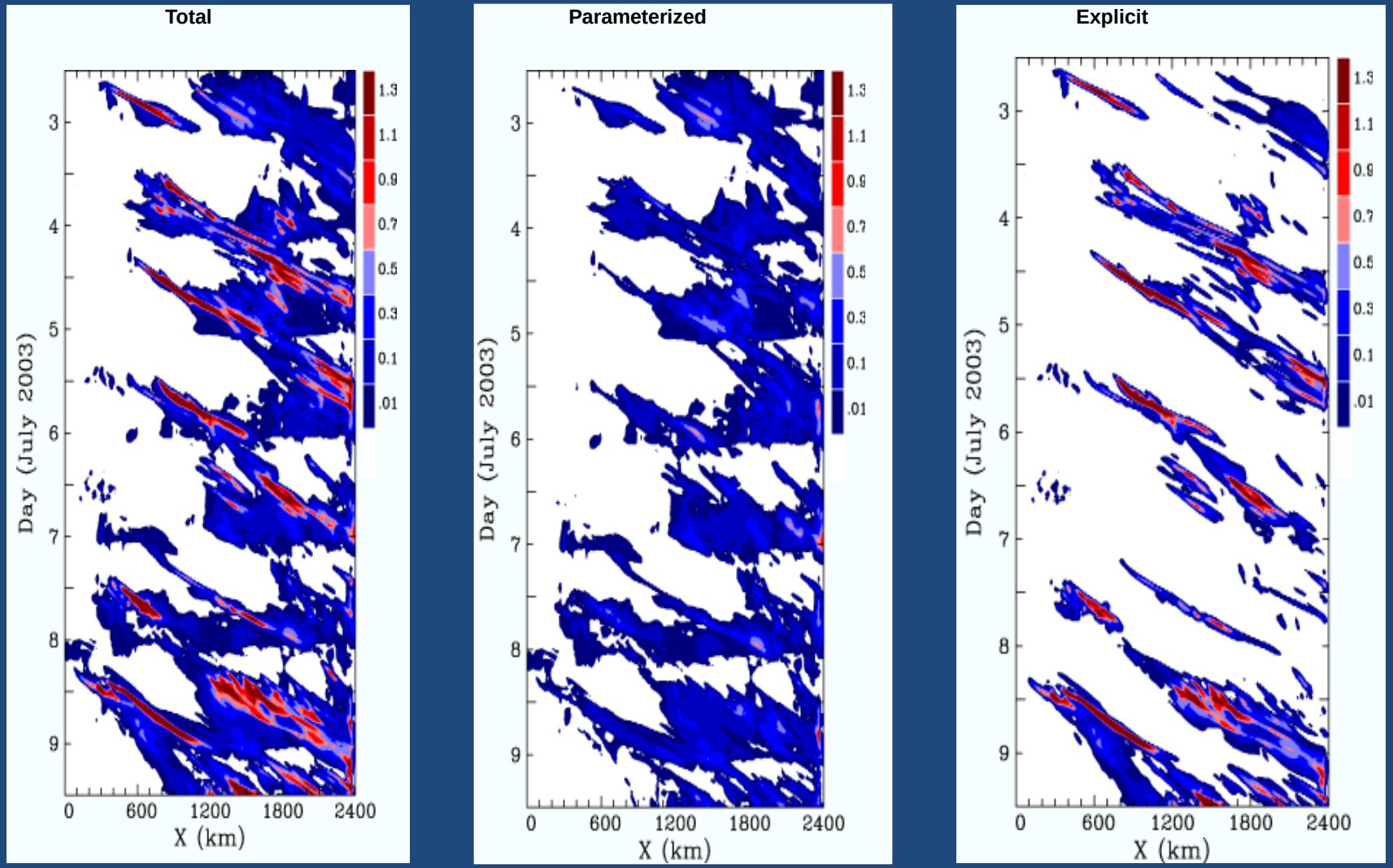
Numerical simulation of summertime organized convection over the continental US



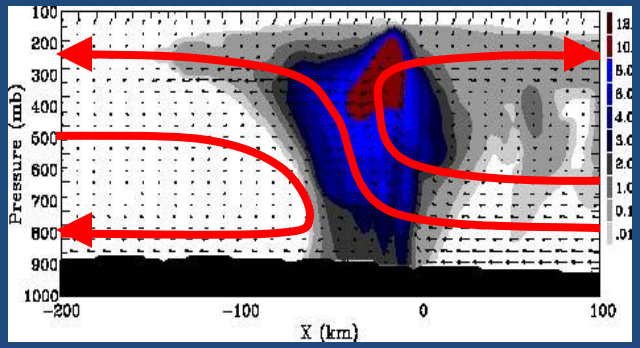
Meridionally averaged rain-rate

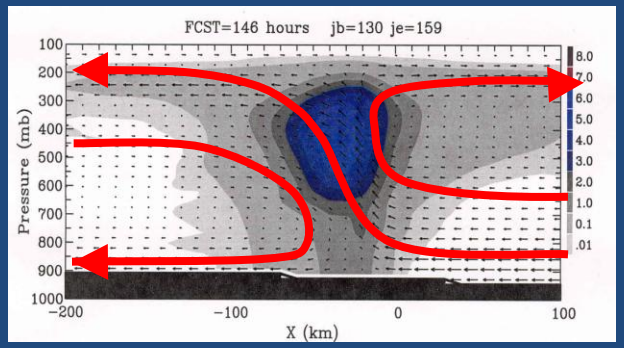


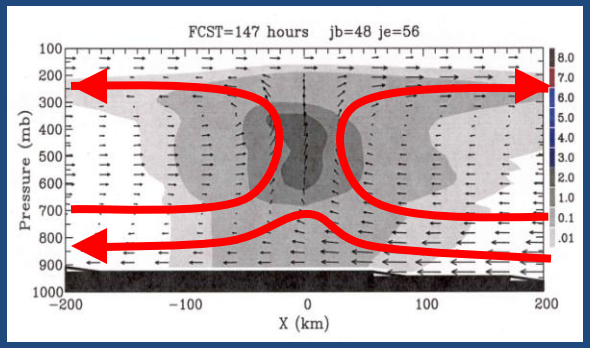
Parameterized & explicit precipitation

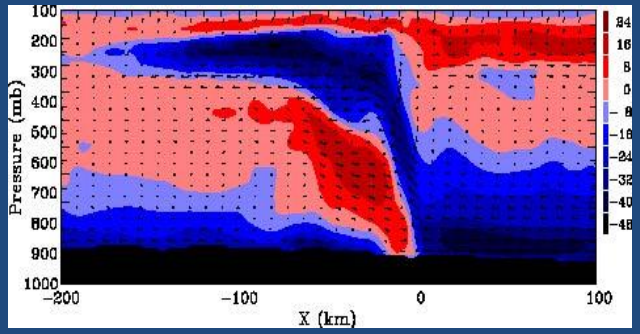


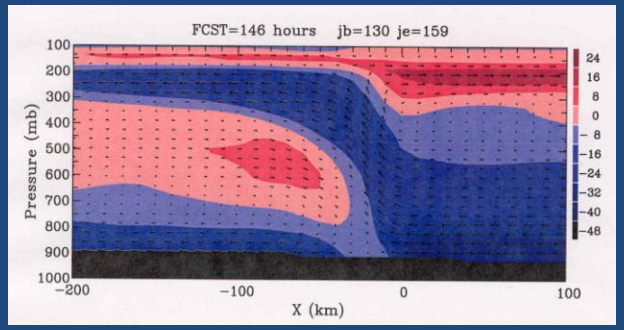
Resolution dependence

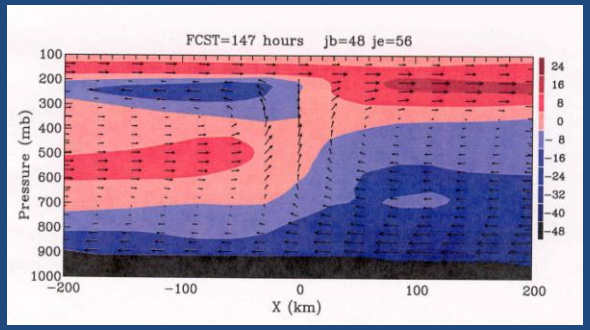








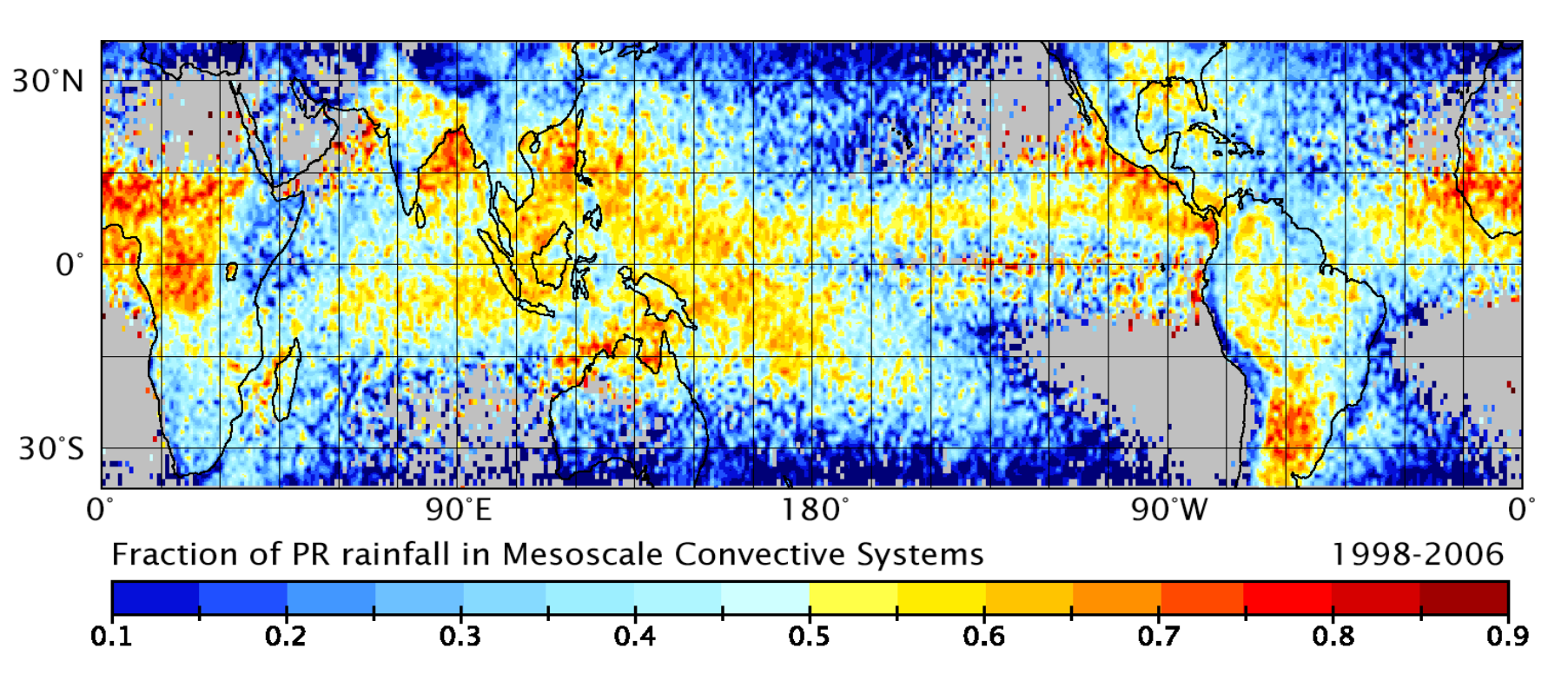




$\Delta = 3$ km $\Delta = 10$ km $\Delta = 30$ km

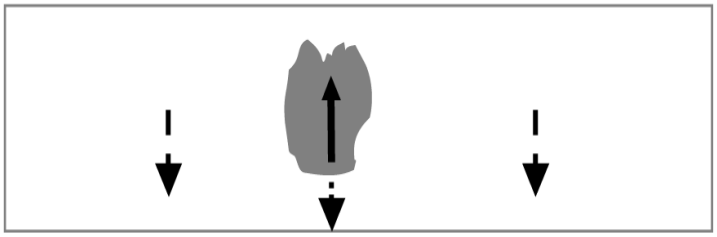
3-km & 10-km -- similar convective organization, amplitude too weak in 10 km
30-km – unrealistic

Global importance of MCS



Convective parameterizations do not represent organized dynamics

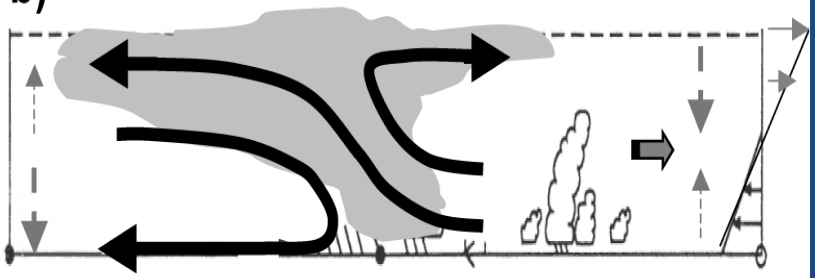
a)



Isolated convection, single grid volume

- Entraining plume (turbulent mixing)
- No environmental shear
- Local response
- Closed system
- Weak scale-interaction
- No gravity waves

b)



Organized convective system, many grid volumes

- Organized flow (mesoscale dynamics)
- Environmental shear
- Local and remote response
- Open system
- Strong scale-interaction
- Convectively-generated gravity waves

Conclusions

- MCS-type convective organization occurs at different scales in explicit models

- Scale-gap of traditional convective parameterization been bridged, realistic mesoscale circulations in explicit models even 10-km-grid models

- Meso-convective organization (mesoscale dynamics) spontaneous in: global CRMs, superparameterized models (MMF), tropical channel models

- Relevant for seamless climate prediction, especially in terms of the distribution of precipitation and the diurnal cycle

- Meso-convective dynamics an important element of the "upscale cascade"

- Mesoscale circulations in 10-km-grid climate models occur as a hybrid parameterization, an improvement over traditional parameterization

- Challenge: representing meso-convective organization in traditional parameterizations